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Modeling a Miniaturized Scanning Electron Microscope Focusing Column—Lessons Learned in Electron Optics Simulation

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This presentation discusses work done to assess the design of a focusing column in a miniaturized Scanning Electron Microscope (SEM) developed at the NASA Marshall Space Flight Center (MSFC) for use in-situ on the Moon—in particular for mineralogical analysis. The MSFC beam column design uses purely electrostatic fields for focusing, because of the severe constraints on mass and electrical power consumption imposed by the goals of lunar exploration and of spaceflight in general.

The resolution of an SEM ultimately depends on the size of the focused spot of the scanning beam probe, for which the stated goal here is a diameter of 10 nanometers. Optical aberrations are the main challenge to this performance goal, because they blur the ideal geometrical optical image of the electron source, effectively widening the ideal spot size of the beam probe. In the present work the optical aberrations of the mini SEM focusing column were assessed using direct tracing of non-paraxial rays, as opposed to mathematical estimates of aberrations based on paraxial ray-traces. The geometrical ray-tracing employed here is completely analogous to ray-tracing as conventionally understood in the realm of photon optics, with the major difference being that in electron optics the lens is simply a smoothly varying electric field in vacuum, formed by precisely machined electrodes. Ray-tracing in this context, therefore, relies upon a model of the electrostatic field inside the focusing column to provide the mathematical description of the “lens” being traced. This work relied fundamentally on the boundary element method (BEM) for this electric field model. In carrying out this research the authors discovered that higher accuracy in the field model was essential if aberrations were to be reliably assessed using direct ray-tracing. This lead to some work in testing alternative techniques for modeling the electrostatic field. Ultimately, the necessary accuracy was attained using a BEM/Fourier series hybrid approach.

The presentation will give background remarks about the MSFC mini Lunar SEM concept and electron optics modeling, followed by a description of the alternate field modeling techniques that were tried, along with their incorporation into a ray-trace simulation. Next, the validation of this simulation against commercially available software will be discussed using an example lens as a test case. Then, the efficacy of aberration assessment using direct ray-tracing will be demonstrated, using this same validation case. The discussion will include practical error checks of the field solution. Finally, the ray-trace assessment of the MSFC mini Lunar SEM concept will be shown and discussed.

The authors believe this presentation will be of general interest to practitioners of modeling and simulation, as well as those with a general optics background. Because electron optics and photon optics share many basic concepts (e.g., lenses, images, aberrations, etc.), the appeal of this presentation need not be restricted to just those interested in charged particle optics.